Prospects for a nuclear optical frequency standard based on Thorium-229

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The nucleus of ^{229}Th has the lowest-lying excited state known in nuclear physics. A recent high-resolution γ-spectroscopic investigation indicates an excitation energy in the range of 7.6 ± 0.5 eV [1]. The isomeric state decays to the ground state predominantly through a magnetic dipole transition with an expected unperturbed lifetime in the range of 5000 s [2]. The expected transition wavelength is in a part of the VUV range that is accessible by frequency upconversion of narrow-bandwidth continuous and phase-coherent femtosecond laser sources. Thus it appears possible to measure the nuclear energy level splitting of ^{229}Th with the precision afforded by high-resolution laser spectroscopy and optical frequency metrology. Nuclear transition frequencies are much more stable against external perturbations than transition frequencies of the electron shell because the characteristic nuclear dimensions are small compared to the atomic dimension. Therefore nuclear transitions in laser-cooled trapped ions are attractive as highly accurate frequency references. Estimates on the magnitude of systematic frequency shifts must however also consider the coupling of the nuclear and electronic energy level systems through the Coulomb and hyperfine interactions. Taking this into account, we have investigated the case of $^{229}Th^{3+}$ whose electronic level system appears to be suitable for laser cooling and for the sensitive detection of excitation to the isomeric state using a nuclear-electronic double resonance scheme. For operation at room temperature, the largest perturbation would arise from the hyperfine Stark shift caused by the ambient blackbody radiation. The resulting shift of the observed nuclear transition frequency has an estimated relative magnitude of 10^{-19} [3].

It appears that up to now, all experiments aiming at the direct observation and optical spectroscopy of the isomeric transition of ^{229}Th have been unsuccessful. Most experiments used solid or liquid samples whose isomeric ^{229}Th content originated from the α-decay of ^{233}U. The failure to detect the isomeric transition is likely due to the fact that earlier γ-spectroscopic work had suggested a significantly lower transition energy in the range of 3.5 eV [4] and that the experiments were not sensitive in the range around 7.6 eV. We are extending these studies into the VUV region, looking at the emission of bulk ^{233}U samples and of freshly produced ^{229}Th recoil nuclei. In addition, we investigate the possibility of exciting the isomeric transition by multiphoton excitation of the electron shell of $^{229}Th^{+}$ ions confined in a radiofrequency trap.

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